NRC–NIST Comparison of Power Meter Calibrations at 60 Hz and Ranges up to 600 V, 100 A

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***Abstract*—A number of international comparisons of power meter calibrations at power frequencies were conducted in the past, all of them being done at 120 V and 5 A. This comparison of power meter calibrations between the National Research Council of Canada and the National Institute of Standards and Technology, USA, was done to include voltage ranges up to 600 V, current ranges up to 100 A, and at power factors of 1.0, 0.5 lead and lag, and 0.0 lead and lag. The comparison was implemented by a transfer standard consisting of a modified commercial time-division multiplier type wattmeter based on a development at the National Research Council of Canada. The results indicate that there are no significant differences in the overall accuracy of ac power measurements in each laboratory up to 600 V, 100 A, at all power factors.**

***Index Terms*—International comparison, power meter calibrations.**

I. Introduction

POWER meter calibrations are usually done at 120 V and 5 A. However, many commercial power meters have ranges up to, or higher than, 600 V and 100 A. National laboratories, in particular the National Research Council of Canada (NRC) and the National Institute of Standards and Technology (NIST), have received requests from the industry to provide calibrations at voltages higher than 120 V and currents higher than 5 A. Therefore, NRC and NIST have extended their power meter calibration systems to address these requests. This paper describes the comparison of the two systems at 60 Hz and voltage ranges of 120 V, 240 V, 360 V, 480 V, and 600 V, and current ranges of 5 A, 50 A, and 100 A, at power factors of 1.0, 0.5 lead and lag, and 0.0 lead and lag. The comparison was implemented using a commercial time-division multiplier type wattmeter, based on a development at NRC [1], as a transfer standard. The wattmeter was modified to include voltage ranges up to 600 V and current ranges up to 100 A. At power frequencies the wattmeter has errors of less than 30×10^{-6} of full-scale apparent power for all power factors at voltage ranges up to 600 V and current ranges up to 100 A.

This comparison was done as part of a North American Metrology Cooperation (NORAMET) program to address mutual confidence in calibration services of active/reactive power and energy meters at voltage ranges up to 600 V and current ranges up to 100 A. It will be repeated again in the near future to include the national laboratory of Mexico, Centro National de Metrologia (CENAM), upon completion of the voltage and current range extensions of their power meter calibration system.

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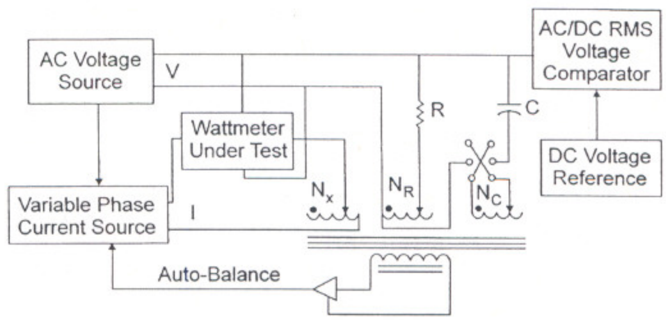

Fig. 1. NRC calibration system.

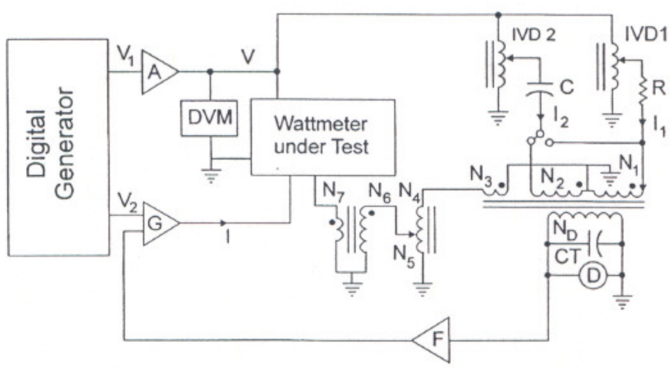

Fig. 2. NIST calibration system.

II. Calibration Systems

A. NRC Calibration System

The basic circuit of the NRC calibration system [2] is shown in Fig. 1. The test current is obtained from a variable phase current source based on a transconductance amplifier. The actual test condition of the wattmeter under test is established by using a current comparator to compare the test current with in-phase and quadrature reference currents derived by applying the test voltage to a reference resistor and an active reference capacitor [3]. The current comparator determines small deficiencies in the ampere-turn balance and by feedback adjusts the output of the current source to realize the desired test conditions. When the feedback is operative, the test condition is held constant relative to the test voltage. Variations in the voltage are measured by the ac/dc comparator and transferred to the microcomputer

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TABLE I
CALIBRATION RESULTS AT NRC AND NIST, μW/W OF APPARENT POWER

(a) NRC

Power	120V			240V			360V			480V			600V		
Factor	5A	50A	100A	5A	50A	100A	5A	50A	100A	5A	50A	100A	5A	50A	100A
1	-5	-14	-12	-1	-8	-9	2	-8	-7	5	-4	-3	2	-9	-8
0.5 Lead	5	-10	-7	9	-6	-3	0	-12	-12	5	-8	-7	8	-8	-6
0.5 Lag	-2	3	7	-1	3	5	7	12	14	8	13	14	0	8	7
0 Lag	3	15	18	1	13	15	10	21	23	8	19	22	1	15	16
0 Lead	10	0	2	11	1	4	3	-8	-7	5	-6	-5	11	-2	0

(b) NIST

Power	120V			240V			360V			480V			600V		
Factor	5A	50A	100A	5A	50A	100A	5A	50A	100A	5A	50A	100A	5A	50A	100A
1	3	-17	-15	-3	-4	-2	6	7	3	12	-1	4	8	-4	-2
0.5 Lead	7	-5	-2	9	-3	4	11	-12	-4	20	-6	0	26	-5	6
0.5 Lag	-1	-3	-1	-1	10	7	0	21	16	-1	18	11	-6	10	7
0 Lag	2	2	4	4	14	3	-6	26	16	-8	20	10	-13	13	8
0 Lead	13	6	7	20	2	9	9	-17	-7	16	-6	-1	24	0	7

(c) NIST - NRC

Power	120V			240V			360V			480V			600V		
Factor	5A	50A	100A	5A	50A	100A	5A	50A	100A	5A	50A	100A	5A	50A	100A
1	8	-3	-3	-2	4	7	4	15	10	7	3	7	6	5	6
0.5 Lead	2	5	5	0	3	7	11	0	8	15	2	7	18	3	12
0.5 Lag	1	-6	-8	0	7	2	-7	9	2	-9	5	-3	-6	2	0
0 Lag	-1	-13	-14	3	1	-12	-16	5	-7	-16	1	-12	-14	-2	-8
0 Lead	3	6	5	9	1	5	6	-9	0	11	0	4	13	2	7

for inclusion in the error calculation. Extension of the power bridge to 600 V and 100 A is accomplished using a current-comparator-based capacitive voltage divider [4] and a two-stage current transformer.

The calibration system is energized from a 400-Hz source. The test frequency is derived from a crystal controlled oscillator and, if it is nominally the same as the local power frequency, the instrument power circuits are supplied from another oscillator, which can be phase-locked at any angle to the test frequency. Any interference between the test and power circuits can, therefore, be detected by varying this phase angle while calibrating the instrument under otherwise identical conditions.

B. NIST Calibration System

The NIST calibration system [5] is shown in Fig. 2. Although the system is also based on the use of a current comparator, the operating principle is different than that of the NRC system. The currents are scaled to the working level by different methods. The wattmeter under test is supplied by a digitally synthesized source having separate voltage and current channels. A high voltage capacitance bridge is used in place of the special current comparator to establish the test conditions. High sensitivity and large ratios of the capacitance bridge enable the use of high impedances, such as stable gas-dielectric capacitors and resistors having low-power dissipation for the generation of reference currents. Inductive voltage dividers are used to adjust the reference currents to obtain test conditions of any power factor between zero and one, lead and lag. The test voltage is measured using a sampling digital voltmeter. Extension of the voltage and current ranges is accomplished using a resistive voltage divider compensated with an active circuit [6] and an amplifier-aided two-stage current transformer (not shown in Fig. 2). Normally for 50 Hz and 60 Hz tests, the bridge and wattmeter under test are powered at 70 Hz. Influences of power line interference are measured by powering the wattmeter at the same frequency as the test and adjusting the relative phase between the two.

III. MEASUREMENT RESULTS

The measurement result for each test condition is the average of the results of at least five measurements made over a period of several days. Table I shows the measurement results obtained by the two laboratories, and the differences of the results. The standard deviations of all results for each test condition were less than 10×10^{-6} of full-scale apparent power. The NRC results were obtained from the average of two sets of measurements taken at the start and at the end of the comparison. These results are taken as the base values for the comparison and as the best values for the errors of the transfer instrument. At 120 V, 5 A, the differences were found to be no more than 8×10^{-6} of full-scale apparent power. These results confirm the agreement between the two systems at power frequencies at 120 V, 5 A, in another comparison using a different transfer standard [7]. At all other voltages up to 600 V and currents up to 100 A, the two systems agreed within 20×10^{-6} of full-scale apparent power.

The degree of agreement in the comparison is determined by the uncertainties in the results of the ac power measurements at each laboratory and the stability of the transfer instrument. Although the NRC and NIST systems have different operating principles, their total uncertainties are of the same order of magnitude. Sources of uncertainty of the calibration systems are described in [2] and [5]. Their total uncertainties $(1 - \sigma)$ at all power factors are less than 10×10^{-6} of full-scale apparent power at 120 V, 5 A, and less than 15×10^{-6} of full-scale apparent power at higher voltages and currents. The uncertainty at higher voltages and currents includes the uncertainties of the range extenders for voltage and current. The stability of the transfer device at all voltage and current ranges, based on measurement results taken over a longer period of time at NRC, is better than 10×10^{-6} of apparent power at all test power factors. Therefore, based on the results shown in Table I, it can be concluded that within the uncertainty of the measurements, there are no significant differences in the overall accuracy of ac power measurements at voltage ranges up to 600 V and current ranges up to 100 A in each laboratory.

IV. Conclusion

The test results indicate that the power meter calibration systems of NRC and NIST at power frequencies, voltages of up to 600 V, and currents up to 100 A are in agreement within the uncertainty of the measurements.

References

[1] P. Filipski, "A TDM wattmeter with 0.5-MHz carrier frequency," *IEEE Trans. Instrum. Meas.*, vol. 39, pp. 15–18, Feb. 1990.

[2] W. J. M. Moore and E. So, "A current-comparator-based system for calibrating active/reactive power and energy meters," *IEEE Trans. Instrum. Meas.*, vol. 32, pp. 147–149, Mar. 1983.

[3] E. So and W. J. M. Moore, "A stable and accurate current-comparator-based quadrature-current reference for power frequencies," *IEEE Trans. Instrum. Meas.*, vol. 31, pp. 43–46, Mar. 1982.

[4] E. So, "The application of the current comparator in instrumentation for high voltage power measurements at very low power factors," *IEEE Trans. Power Delivery*, vol. 1, pp. 98–104, Jan. 1986.

[5] N. M. Oldham and O. Petersons, "Calibration of standard wattmeters using a capacitance bridge and a digital generator," *IEEE Trans. Instrum. Meas.*, vol. 34, pp. 521–524, Dec. 1985.

[6] O. Petersons, T. L. Nelson, N. M. Oldham, and G. J. Fitzpatrick, "Extension of voltage range for power and energy calibrations," *IEEE Trans. Instrum. Meas.*, vol. 48, pp. 439–443, Apr. 1999.

[7] N. Oldham *et al.*, "International comparison of 50/60 Hz power (1996–1999)," *IEEE Trans. Instrum. Meas.*, vol. 50, pp. 356–360, Apr. 2001.